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Study on safety capacity of chemical industrial park in operation stage

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Abstract

It's important for the safety planning of the chemical industrial park to calculate the safety capacity of the park as chemical industrial parks developed fast in recent decades in our country. This paper defined the safety capacity of chemical industrial park and improved the calculation methods which had been presented. The safety capacity of chemical industrial park could be calculated by using the indictors of the safety capacity (individual risk, social risk and potential risk), in the basic information of the park, such as the production scale of enterprises in the park, layout and the population distribution and so on. The new method presented the concepts of hazardous chemicals equivalent to research the impact of the hazardous chemicals species to the safety capacity. The effect of population distribution will also be considered when calculating the safety capacity. Besides, the domino effect should be discussed to fix the safety capacity of the chemical industrial park when the park is at full load condition. Then, the real safety capacity of the park could be calculated. Finally, the analysis process of the appropriate safety capacity is illustrated with an application example in a certain chemical industrial park.

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Keywords: Chemical industrial park; safety capacity; operation stage; domino effect

1. Introduction

A great number of chemical industrial parks have been constructed, with the development of the chemical industry, in recent years [1]. According to statistics, there have been thousands of provincial and national chemical industrial parks in China. Chemical industrial parks have become major sources of accidents and environmental

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pollution which threaten human life and property safety, when they promoting the development of China's chemical industry [2]. The trend of companies focusing ever stronger on their core businesses has led to outsourcing of certain activities, e.g. maintenance, and even to selling out parts of industrial plants. In these multi-company parks safety and environmental responsibilities are not always clear and the risk map has changed [3]. Besides, In order to seek more benefits, many enterprises expand the scale of production immoderately. In this case, the quantity of hazardous chemicals is far beyond the safety capacity of the park. Some researchers have pointed out that the number of chemicals hazardous chemicals is the main cause excessive serious consequences of the accident. Therefore, how to determine the safety capacity of a chemical industrial park scientifically and reasonably become a serious problem in china.

The indicators and calculation models of the safety capacity of chemical industrial park have been presented to meet these needs. CHEN xiaodong and DUO yingquan [2,4] (2009) defined safety capacity of chemical industrial park as a risk-associated threshold which is the amount of hazardous chemicals determined by the production risks, storage risks, transportation risks, usage risks and other risks jointly within the affordable range of overall risk. LI chuangui, WANG weiguo et al.[5,6] proposed a new concept: risk capacity of chemical industrial park and calculate the safety capacity using the assessment indicators of accidents. This model takes the park site, park master plan, focusing on managed objects, fire planning and safety management into consideration to fix the safety capacity of the park. TAN xiaoqun [7] (2011) defined safety capacity of chemical industrial park as the total amount of hazardous chemicals determined by both maximum stock amount and maximum transportation amount. This model defines the equivalent of hazardous chemicals and average risk value to calculate the safety capacity of the park.

There are some deficiencies in the calculation models of safety capacity. First, the models are in poor operability. It is difficult to calculating safety capacity using these models because of the lack of the basic data. Secondly, these models can only be used in ideal circumstances. And they are without considering the effects of hazardous chemical species, the distribution of dangerous chemicals, domino effect between sources, the population distribution and other factors to safety capacity. Thus, the calculation safety capacity is not accurate. For these shortcomings, this paper aims to propose a relative simple and accurate calculation method for the safety capacity of chemical industrial park in operation stage and hope that will be useful for the safety management of chemical industrial park.

2. Safety capacity of chemical industrial park in operation stage

2.1. Characteristics of Chemical Industrial Park in Operation stage

Each type of chemical industrial parks contains different life cycle stages. The life cycle of the park can be divided into design stage, construction stage and the operation stage from the characteristics of chemical industrial park. The main security issues and the calculation model are different in different stages of chemical industrial park. This paper takes the operation stage as example research the safety capacity of chemical industrial park. Being different from the design stage, the main security issue which we should concern about is how to determine the maximum quality of the hazardous chemicals when the individual risk because the information is comprehensive.

Basic information about the chemical industrial park we can get is limited and different in the different stage of park. The basic information is more comprehensive in operation stage because of the stable operating condition. The information we can get in operation stage is shown in Table 1.

Table 1. Basic Information of Chemical Industrial Park in Operation Stage.

Type	specific contents
Enterprise basic information	The type of the enterprise, the production scale of enterprises in the park, layout and the population distribution and so on.
Hazardous chemicals information	Hazardous chemical species, reserves and turnover of dangerous chemicals and so on.
Equipment and facilities basic information	The type, size, scale and operating parameters of equipment and so on.
Safety management	Management structure, staffing and so on.
Emergency management	Emergency rescue plan, emergency relief agencies, personnel and equipment facilities and so on.

2.2. Definition of safety capacity of chemical industrial park in operation stage

The safety capacity of chemical industrial park is evolved on the basis of quantitative risk assessment. The specific definition of safety capacity is not unified at present [4]. However, many scholars agreed that the safety capacity of chemical industrial park related to the number and nature of hazardous chemicals, equipment and facilities, production process conditions, population distribution, land use and regional planning and risk control measures. Therefore, the safety capacity of chemical industrial park could be defined as: The safety capacity of the chemical industrial park is the maximum quantity of hazardous chemicals when the level of risk in the chemical park is under the acceptable level. The safety of chemical industrial park could be accepted only when the quantity of hazardous chemicals not exceed the safety capacity.

2.3. Indicators of Safety Capacity

The quantitative risk assessment should be used in the analysis of safety capacity of chemical industrial park. Thus, the indicators of safety capacity should also be Individual risk, social risk and the potential loss of life.

- Individual Risk

Individual risk is the frequency at which an individual may be expected to sustain a given level of harm from the realization of specified hazards. Typically measured as a probability of fatality per year [8]. Many foreign countries and regions, such as the Netherlands, Norway, UK, USA, Singapore, Hong Kong and so on, have developed a corresponding individual risk criteria according to the situation in the region.

- Social Risk

Societal risk is the relationship between the frequency and the number of people suffering from a specified level of harm in a given population from the realization of specified hazards [8]. Social risk allow the principle the of ALARP (As Low As Reasonable Practice).

- Potential Loss of Life

Probable loss of life (PLL) is a numeric combination of the frequency of number of fatalities for unwanted events. The PLL is a type of risk integral [8]. PLL consider the impact of both the individual risk of death and the total population in the area. It's a unified characterization of frequency and consequences of accidents. The potential loss of life is a better indicator than the individual risk when considering the impact of the population distribution.

3. Model of safety capacity of chemical industrial park in operation stage

3.1. Calculation process of the safety capacity

The operating condition of chemical industrial park is stabilized. The calculation model of safety capacity could be built and the safety capacity of sample which be chosen could be calculated by using the indictors of the safety capacity (individual risk, social risk and potential risk), in the basic information of the park, such as the production scale of enterprises in the park, layout and the population distribution and so on. The impact of population distribution and hazardous chemical species should be considered when calculating the safety capacity. The domino effect should be discussed to fix the safety capacity of the chemical industrial park when the park is at full capacity. Then, the real safety capacity of the sample could be calculated and the park. The calculation process of the safety capacity of chemical industrial park is shown in Fig. 1.

3.2. Collect the basic information of chemical industrial park

The basic information of the chemical industrial park in operation stage could be got through the chemical technology files, process flow diagrams, equipment and facilities layout and the field research companies in the park. The information includes enterprise basic information, hazardous chemicals information, equipment and facilities basic information, safety management and emergency management.

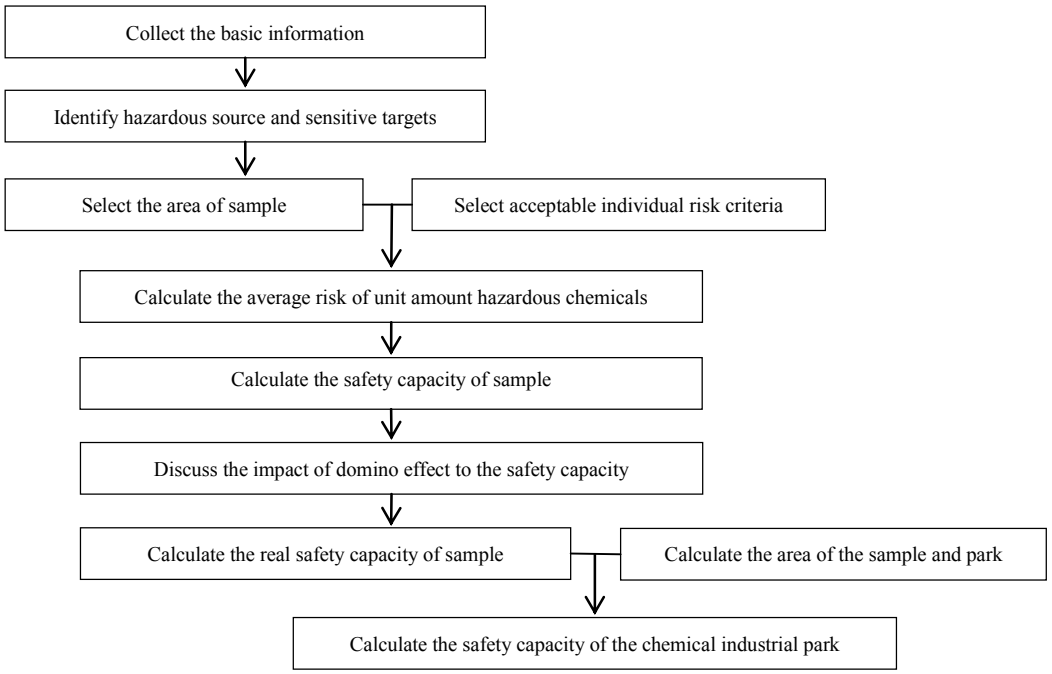

Fig. 1. Calculation process of safety capacity of chemical industrial park.

3.3. Tables

It's important to identify the hazardous source and sensitive targets accurately before analysis the safety capacity of the chemical industrial park in operation stage. The hazards are the hazardous chemicals and production and storage facilities in non-normal state. The sensitive targets include office area, residential district, community centers and so on.

3.4. Select the area of sample

In China, the most important feature of the chemical park is the large scale and the centralization of enterprises in the park. Calculating the safety capacity of the whole chemical industrial park accurately is difficult and unnecessary because of the complication of the production run status and social environment in operation stage. More scientific approach is calculating the safety capacity of a particular area according to the needs or deduce the safety capacity of the park through the research of a representative area which be chosen. Choosing a representative area as a sample is much necessary when calculating the safety capacity of the chemical industrial park.

More scientific approach is based on a particular area of need for the park's security capacity is calculated, or in a representative area for the study, and then derive the security capacity of the entire chemical industrial park. Therefore, when calculating the capacity of the entire chemical industrial park security, choose a reasonable analysis of a representative sample of the area as it is extremely necessary. Notably, the choice of the analysis of samples should choose the type of business park major industry is relatively concentrated area.

3.5. Tables

It's the lower the better in terms of individual risk. However, the pursuit of unlimited low-risk criteria dues to the unlimited high costs. Thus, it is clearly unrealistic. It's a key point to select a reasonable and acceptable risk

criterion before calculating the safety capacity. Most Chinese scholars use statistical analysis to determine acceptable risk criteria [9].

The State Administration of Work Safety promulgated Major Hazards of Hazardous Chemicals Supervision Interim Provisions (The 40th order of State Administration of Work Safety) on December 1, 2011. The 40th order proposed the acceptable individual risk criteria for important goals, highly sensitive area and high population density area is 3×10-7 per year and the risk criteria for public gathering places and high-density living area is 1×10^{-6} per year [10]. The acceptable individual risk and social risk criteria of production and storage equipment of hazardous chemicals (try out), which had been promulgated by the State Administration of Work Safety, used the product of the lowest mortality in different age multiply by acceptable risk increase coefficient as the acceptable individual risk level for important goals, highly sensitive area, high population density area, public gathering places and high-density living area [11]. The bigger the regional population density is, the more potential loss of life is at the same individual risk level. The acceptable individual risk criteria should be different because of the different population density. This paper referenced to the relevant domestic and international research achievements and determined the individual risk criteria which are shown in Table 2.

Table 2. Acceptable Individual Risk Criteria.

Objects	Typical Objects	Maximum Acceptable Individual Risk/Per Year
High Population Density Area	Schools, Hospitals, Residential areas and so on.	3×10^{-7}
Medium population density area	Sporadic residential areas, Office buildings, Labour-intensive factories and so on.	3×10^{-6}
Low population density area	Technology-intensive factories, Public square and so on.	1×10^{-5}
Inside the Enterprise	Inside the enterprise in chemical industrial parks.	1×10^{-4}

3.6. Calculate the average risk of unit amount hazardous chemicals

The type of the enterprise, the production scale of enterprises in the park, layout and the population distribution, Hazardous chemical species and reserves and turnover of dangerous chemicals have been identified. Thus, for a certain risk source inside an area, the risk capacity by the risk source can be calculated by the following equation:

$$RC = \sum_{i=1}^{n} PLL_i \tag{1}$$

where RC is risk capacity; PLL_i is potential loss of life generated by a certain hazardous source (i); n is the number of hazardous sources.

The potential loss of life (PLL) is a numeric combination of the frequency of number of fatalities for unwanted events. The PLL by the risk source can be calculated by the following equation [7]:

$$\mathrm{PLL} = \sum_{j=1}^{m} f_j K_j \tag{2}$$

where f_jK_j is accident probability and expected fatalities.

There are many hazardous chemical species in the chemical industrial park. The hazardous characteristics of hazardous chemicals are different because of the difference of the hazardous chemical species. In order to consider

the impact of the difference of the hazardous chemical species, this paper referred to the contents of *Major Hazards of Hazardous Chemicals Supervision Interim Provisions* (*The 40th order of State Administration of Work Safety*) and proposed a method to calculate the hazardous chemicals equivalent (*C*).

$$C = \beta_1 C_1 + \beta_2 C_2 + \cdots + \beta_n C_n \tag{3}$$

where $\beta_1, \beta_2 \ldots \beta_n$ is correction coefficient; $C_1, C_2 \ldots C_n$ is quantity of all kinds of dangerous chemicals in the sample area. The value of correction coefficient (β) is shown in Table 3 and Table 4 [11].

Table 3. Value of Correction Coefficient (β).

Species of Hazardous Chemicals	Poisonous Gas	Explosives	Flammable Gas	Others
β	Shown in Table 3	2	1.5	1

Table 4. Value of Correction Coefficient (β) for Common Poisonous Gas.

Poisonous Gas	Carbon Monoxide	Sulphur Dioxide	Ammonia	Ethylene Oxide	hydrogen chloride	Methyl Bromide	Chlorine
β	2	2	2	2	3	3	4
Poisonous Gas	Hydrogen Sulphide	Hydrogen Fluoride	Nitrogen Dioxide	Hydrocyanic Acid	Carbonyl Chloride	hydrogen phosphide	Methyl Isocyanides
β	5	5	10	10	20	20	20

Note: the value of correction coefficient (β) of poisonous gases which are not in the table 4 is 2 and the highly toxic gas is 4.

The average risk of unit amount hazardous chemicals could be calculated from the above analysis [7].

$$\bar{R} = {RC}/{(N \times C_{exist})} \tag{4}$$

where $\bar{R}$ is average risk of unit amount hazardous chemicals for the sample area which been chosen; N is the total population of the region; C_{exist} is the dangerous chemicals equivalent of a sample area.

3.7. Safety Capacity of the Sample

The safety capacity of the sample could be calculated by using the average risk of unit amount hazardous chemicals and acceptable individual risk level.

$$\bar{R} = {RC}/{(N \times C_{exist})} \tag{5}$$

where C_m is the ideal safety capacity of the sample; R_{limit} is acceptable individual risk level.

3.8. Impact of the Domino Effect to Safety Capacity

The domino effect is defined as a cascade of events in which the consequences of previous accidents are increased spatially and temporally by following ones, thus leading to a major accident (Delvosalle, 1996)[12]. The hazardous sources are concentrated because of the dense model of the enterprises in the chemical industrial park. It's likely to cause the domino effect when an accident happened in the park. Thus, the impact of the domino effect cannot be ignored. Currently, the domino effect had been researched for many years at home and abroad. Some scholars had presented a new method to calculate the domino effect [13]. Failure probability of the facilities can be assessed easily and safety capacity can be fixed. For example, if the accident probability of the hazardous source

becomes the double when considering the impact of the domino effect, then the safety capacity could be the half. By this way, the real safety capacity of the sample will be clear.

3.9. Safety capacity of the chemical industrial park

The safety capacity of the chemical industrial park can be calculated by the following equation:

$$C^* = C_{act} \frac{S}{S_1} \tag{6}$$

where C^* is safety capacity of the chemical industrial park; C_{act} is the real safety capacity of the sample; S is the area of the chemical industrial park; S_1 is the area of the sample.

This paper improved the calculation methods which had been presented. The new method had the advantages of its own. First, this paper presented the viewpoint that the main security issues and the calculation model are different in different stages of chemical industrial park. Second, the new model avoids the characteristics of the poor operability and the complicated operations and computing process. The safety capacity could be calculated easily with the application of software using this method. Third, this paper considers the impact of the hazardous chemical species by presenting the concept of hazardous chemicals equivalent. Besides, the analysis of the domino effect between hazardous sources makes the safety capacity of the chemical industrial more accurate and meaningful.

4. Case study

Take a chemical industrial park in south as an example to verify the calculation model in this paper. The area of this chemical park is 5.2 square kilometres. Take a certain area of the park in southeast as the sample. The area of the sample is 0.9 square kilometres and six enterprises located in it a total area of 0.6 square kilometres. There were no residential areas in the park and the number of employees was 2,000. Thus, the population density was about 0.0033 people per square meters. The existing quality of hazardous chemicals is 6000 tons, including ethanol, toluene, chlorine, liquefied petroleum gas, sulphuric acid, nitric acid, phenol and ethylene and so on. The information of the hazardous chemicals is shown in Table 5.

Table 5. Existing Quality of Hazardous Chemicals.

Species of Hazardous Chemicals	Quality of Hazardous Chemicals(t)	hazardous chemicals equivalent(t)
Poisonous Gas	500	2000
Flammable Gas	1000	1500
Others	4500	4500
Total	5500	8000

The potential loss of life is 0.00758 people calculating through the quantitative risk assessment software which was developed by the author's research group. The existing individual risk is 3.79×10^{-6} per year. The existing individual risk contour map is shown in Fig. 2.

The average risk of unit amount hazardous chemicals could be 4.7×10^{-10} per year according to equation 4 and the value of PLL. The level of individual risk what we chose is 1×10^{-5}. Then, the ideal safety capacity of the sample is 2.1277×10^4 tons. The quality of hazardous chemicals according to the original proportion is shown in Table 6.

The hazardous source 5 is in the domino effect area of hazardous source 4. The impact of domino effect to safety capacity could be ignored when there is only a hazardous source to produce a domino effect. Thus, the real safety capacity of the sample (C_{act}) is 2.1277×10^4 tons and the safety capacity of the chemical industrial park is 1.23×10^5 tons. It is worth noting that the impact of domino effect between hazardous sources could not be ignored when the hazardous sources were relatively dense in the park because that the accident probability could be

increased obviously.

Table 6. Safety Capacity of the Sample.

Species of Hazardous Chemicals	Quality of Hazardous Chemicals(*t*)	hazardous chemicals equivalent(*t*)
Poisonous Gas	1330	5320
Flammable Gas	2660	3990
Others	11967	11967
Total	15957	21277

The potential loss of life is 0.01147 calculating by the quantitative risk assessment software when the sample is full load. The corresponding individual risk contour map is shown in Fig. 3. The domino radius of each hazardous source is shown in Table 7.

Table 7. Domino radius of each hazardous source.

Hazardous Source	Domino Radius（m）	Any Other Hazardous Source in Domino Effect Area
2	25.92	NO
3	47.13	NO
4	60.98	Hazardous Source 5
5	25.92	NO
6	14.32	NO

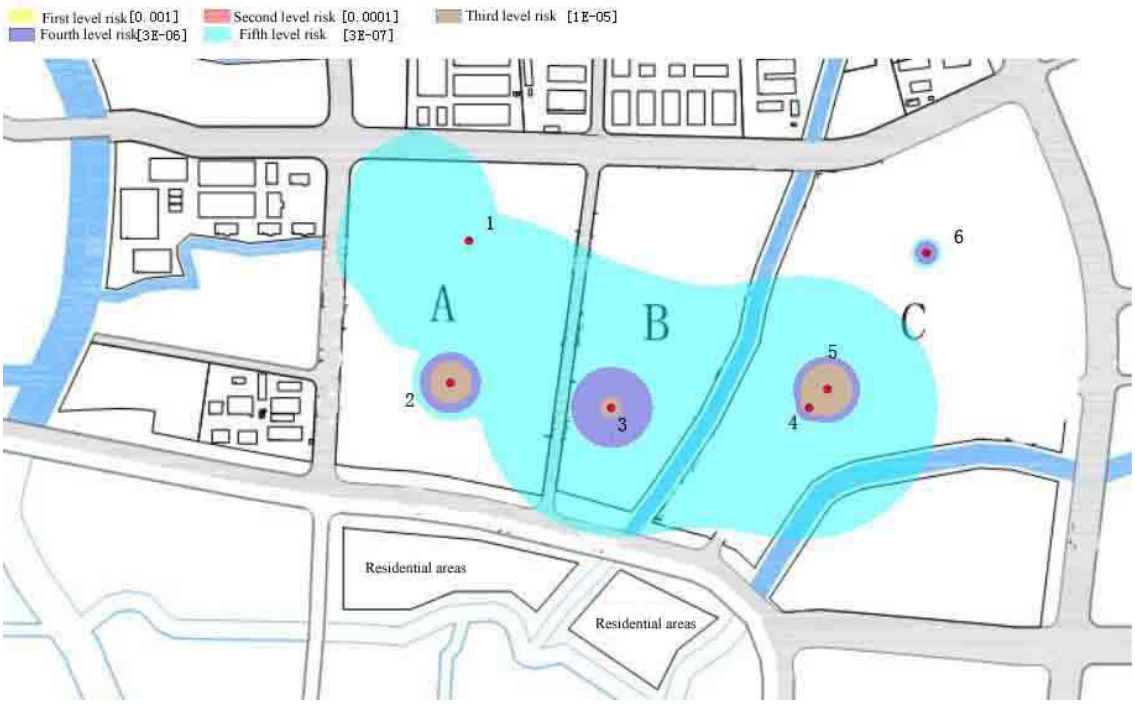

Fig. 2. Existing individual risk contour map.

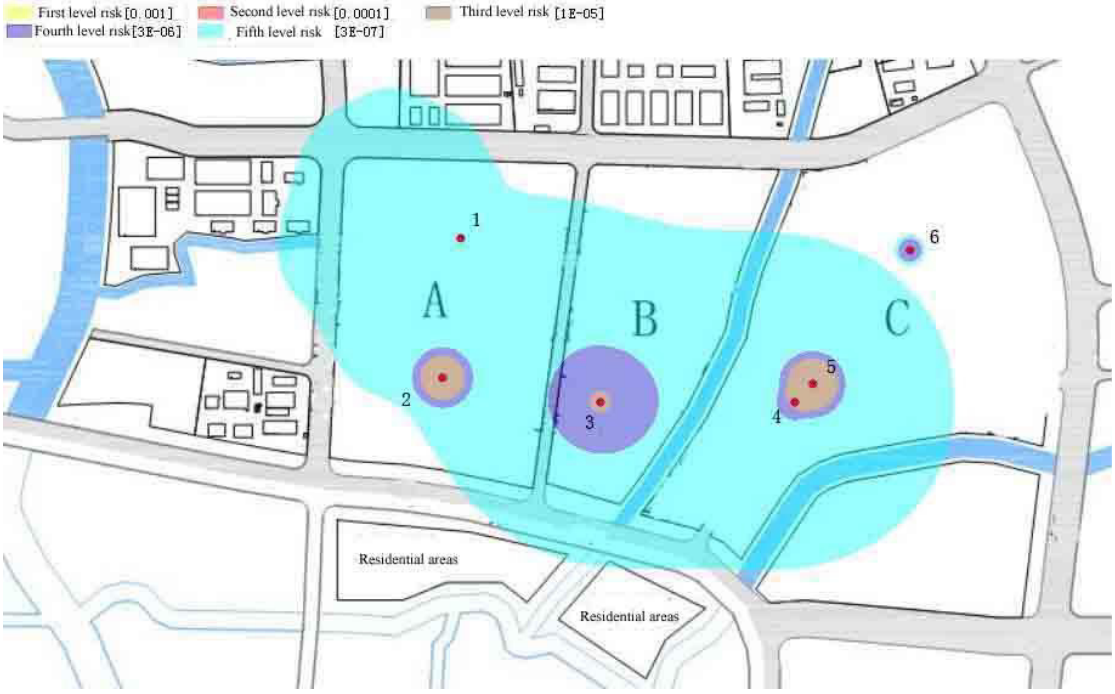

Fig. 3. Individual risk contour map in full load condition.

5. Conclusions

The safety capacity of the chemical industrial park is the maximum quantity of hazardous chemicals when the level of risk in the chemical park is under the acceptable level. This paper improved the calculation methods which had been presented. The new method presented the opinion that the impact of the hazardous characteristics of hazardous chemicals, individual risk level and population density should be considered. Besides, the domino effect should be analysed to fix the safety capacity of the chemical industrial park.

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